INVESTIGATION OF SKIN BURNS BASING ON ACTIVE THERMOGRAPHY

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Abstract - **Use of the dynamic thermography for assessment of burns is discussed. Animal in-vivo experiments are presented – sets of burns were inflicted on the backs of eight domestic pigs. Thermographic measurements of burns with different depth of affected tissue (from the first to the third-degree burns) are correlated with histopathologic analysis of lesions. The results show that dynamic thermography might be advice as a simple, non-invasive and non-stressed for patients diagnostic tool. Further analysis of dynamic pictures gives the first estimate of the depth of a lesion.**

***Keywords – A*ctive thermography, burns, image processing**

I. INTRODUCTION

A reliable, objective, universal and non-invasive method for assessing burn injuries does not exist in today's clinical practice. Such a method would be of a great importance for making proper diagnosis (determination of burn depth and widespread) and for taking decisions about further medical intervention and treatment. Some attempts to introduce classical thermography for assessment of burns were made, e.g. R. Cole [1], M. Liddington [2], but the proposed diagnostic procedure is only qualitative and requires long time of investigation. Also other techniques such as Laser Doppler Imaging [3], Reflection-Optical Multi-spectral Imaging Methods [4, 5] were investigated, but none of these techniques is widely accepted in clinical practice.

We asked [6] if dynamic thermography might be used as an objective, quantitative method for investigation of burns. The preliminary results were very promising therefore we made extended studies basing on *in-vivo* experiments on domestic pigs in controlled conditions with full histopathologic and bacteriologic investigations. Some results are presented here.

The aim of the current study is twofold: a) to develop a reliable mathematical model of skin burns; b) to improve measurement procedures of active thermography and calibrate the measurement set-up for proper classification of burn injures according to the proposed model. The method is basing on measurable, objective tissue properties as thermal conductivity or thermal capacitance. Values of these parameters are related to physiological state of skin and subdermal tissues, its vascularity, pliability and maturation.

II. METHODOLOGY

A. Conditions of the experiment

Eight young boars weighting 20 – 30 kg were used in experiments. The animals were observed and treated against pain or discomfort during the period of 5 days of investigation according to procedures accepted by the local Committee of Ethics and Good Practice. The pigs were maintained under a surgical plane of anaesthesia in conditioned environment of 24 ^{0}C. The back skin was clipped before creation of burns. Aluminium bar (2.5 cm by 2.5 cm and 150 gram weight) and copper roll (diameter d = 4cm and 300 gram weight) were used as applicators for creating burn injury. 11 paired sets of burns were inflicted on the back skin of a pig using aluminium (5 pairs) and copper (6 pairs) bars preheated in hot water to 80^{0}C, 90^{0}C, 100^{0}C and then applied to pig's back for a period of 10, 20 or 30s (see for details Table I). Each pair was representing different conditions of injury giving a set of controlled burn depths. The distribution of burn fields on a pig is shown in Fig. 1.

TABLE I

CONDITIONS FOR GENERATING BUN INJURIES IN EXPERIMENT

	Copper roll: d = 4cm; weight 300g					
	Field 1	*Field 2*	*Field 3*	*Field 4*	*Field 5*	*Field 6*
Temp.[^{0}C]	100	100	100	100	90	80
Time[sec]	10	60	20	30	30	30
	Aluminium roll: 2.5x2.5x9cm; weight = 150g					
	Field 7	*Field 8*	*Field 9*	*Field 10*	*Field 11*	
Temp. [^{0}C]	100	90	80	80	80	
Time [sec]	30	30	30	20	10	

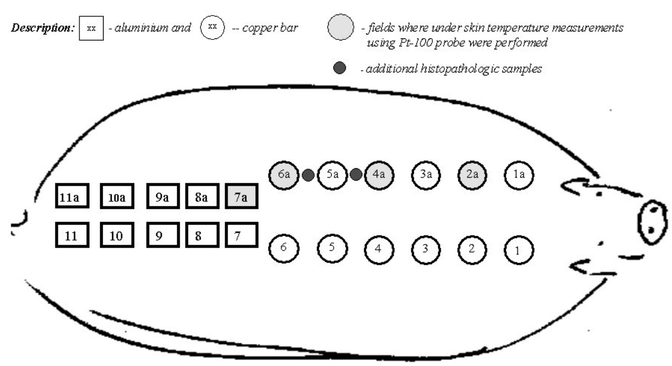

Fig. 1. Location of burn injuries on pig's back.

The total body surface area of burns in each pig was approximately 4 %. In the shaded fields temperature was measured 2 mm under the skin during application of metal bars using miniature Pt-100 probe. Also, changes of the temperature of aluminium and copper bars were recorded using Pt-100 sensors (see schematic placement of sensors in Fig. 2). The full-thickness skin biopsies were collected (for all fields 1a – 11a and for the healthy skin), taken

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approximately 30 minutes after the burn creation. Full histopathologic analysis was performed to give objective data of burn depth.

B. Thermographic measurements

Investigation of burn depth was done using equipment and procedures described earlier [6,7]. The thermographic measurements were performed approximately 0.5 hours after the burn creation and were repeated after 3 and 5 hours and every 24 hours during 5 consecutive days after the injury.

The basic measurement set-up used in our experiments consists of:

- the Agema THV900 thermographic camera system;
- a set of halogen lamps (up to 1000 W) and mechanical shutter;
- a control unit for driving the system.

The hardware allows generation of the following signals of the set of halogen lamps:

- sinusoidal – in the frequency range [0.01Hz – 2.5 Hz];
- pulse – with possibility of settings: – the time duration - $t_I > 10ms$ of each impulse in a train of pulses (package); the period time $T > 10\ ms$; the number of impulses, n, in the package.

In the “Lock-in” procedure four thermograms are recorded for each period of excitation (4-bucked method). In the Pulse Thermography the starting point of recording can be synchronized with the heating or cooling phases or with any other arbitrary chosen delay time. A number of recorded images; recording speed and the stop condition are set from the Erica 3.11 software (*Store Window Menu)*. Images in the cooling phase were collected every second for long time observation (120 seconds) and with maximal frame rate of 30 Hz for the rapid cooling phase lasting 5 seconds. The excitation time 30 seconds of halogen lamps was set during Pulse Thermography procedure. For “Lock-in” procedure three frequencies were mainly used: f=0.1Hz, 0.05Hz and 0.01Hz. For such conditions the excess of evoked skin temperature rise is around 2 – 4 ^{0}C.

The observation by the IR-camera was taken from the distance of 55 cm. For skin thermographic temperature measurements illuminated area was kept dry to satisfy condition of constant evaporation from a tested surface and of a constant value of emissivity coefficient.

III. Results

A. Temperature changes during burn process

The temperature change while heating using copper applicator 2 mm under the skin surface is shown in Fig. 2. Here maximum temperature of subdermal tissue is reached about 40 seconds after removal of the copper roll. The temperature change and distribution depends on thermal properties of a tissue. The observed delay in maximum temperature peak is connected with finite thermal conduction of the tissue.

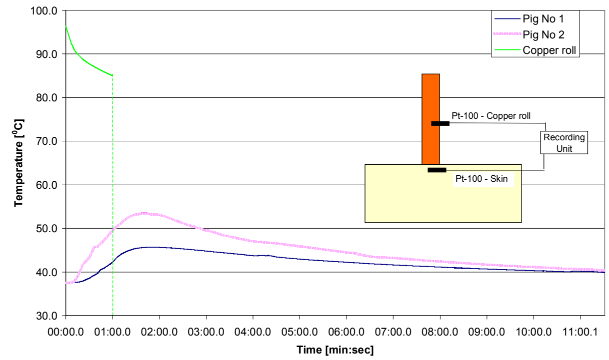


Fig. 2. Placement of Pt-100 probes and the temperature change 2 mm under the skin surface for two different pigs; heating by 100^{0}C copper applicator for the period of 1 minute.

It is clearly seen from Fig. 2 that the change of the subdermal tissue temperature for two pigs (No 1 and No 2) differs significantly. The maximum temperature 2 mm under the skin surface for the pig No 1 equals 53^{0}C and for the pig No 2 - 45^{0}C. This difference of temperature distribution can be generated by a few reasons: the difference of the applied force to metal bars during the burn process; the trouble in the precise placement of Pt-100 sensor under the skin surface and last but not least the physiological difference of the pig’s skin.

The temperature change on the skin surface and 2 mm under the surface is shown in Fig. 3. The data are plot for the pig No 1 - for burn injury caused by the copper roll of the temperature 100^{0}C applied for 60 seconds, as in Fig. 2.

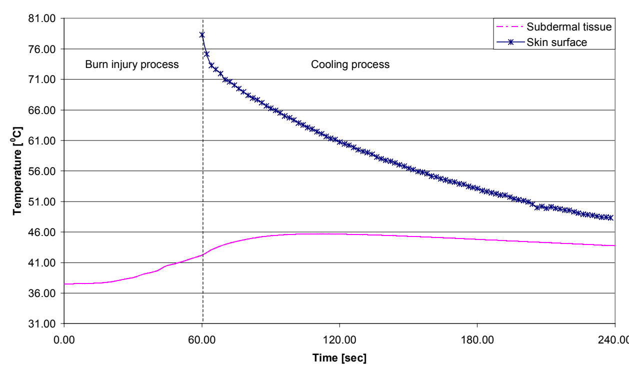


Fig. 3. The temperature changes 2 mm under the surface and on the surface of skin during cooling phase after heating by 100^{0}C copper applicator (heating time of 60 seconds).

After removal of the heat source the temperature of skin surface is instantly dropping down. The heat is dissipated by conduction into deeper layers and irradiated to the surroundings. Heat flow to the environment in natural conditions (without forced convection) is small comparing to conduction to deeper layers of tissue and in further thermal analysis this phenomenon could be neglected.

B. Histopathologic data

Thickness of burns was estimated basing on four parameters evaluated from biopsy according to [8]. One

example of data for the copper roll applications of different temperature but constant time - 30 seconds is shown in Fig. 4. As one can see the generated injury is related to the standard II-nd B and III-rd burn degrees. In clinical practise recognition of the burn degree of that kind is very difficult because there are no existing objective and non-invasive methods for assessment of burn injury but histopathology of biopsies.

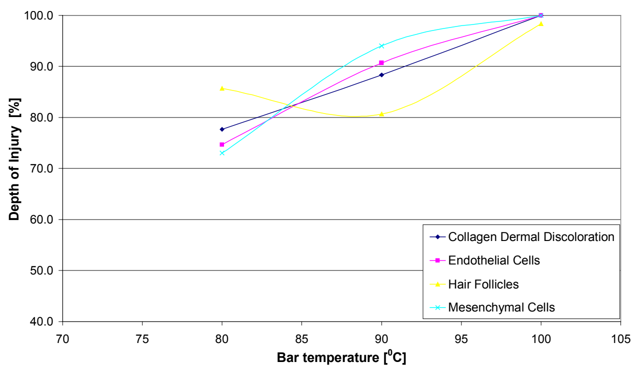


Fig. 4. Determined thickness of burn injuries for several copper roll temperatures and constant time of application – 30 seconds.

The affected thickness of the skin is dependent on temperature and application time of the aluminum and copper bars. From our experience it is also dependent on the applied force to metal bars.

C. Mathematical model of temperature transients

Some kind of preprocessing is needed for fitting thermal data to mathematical model. For Pulse Thermography the normalization procedure basing on equation (1) is advisable:

$$T_{NORM}(x,y,t) = \frac{T(x,y,t) - T_{\min}(x,y)}{T(x,y,0) - T_{\min}(x,y)}, \tag{1}$$

where: *x, y* – pixel co-ordinates, *0* – moment when excitation is switched off, T_{min} – minimum temperature in the recorded sequence. For the time t = 0, distribution of normalized temperature index T_{NORM} equals 1. The differences between pixels related to different thermal properties appear during observation time as it is shown in Fig. 5. For normalized data the fitting curve procedure using the Levenberg-Marquardt algorithm is applied. The best results are obtained for the two exponential model described by the equation:

$$T(t) = A_0 + A_1 e^{-\frac{t}{\tau_1}} + A_2 e^{-\frac{t}{\tau_2}}. \tag{2}$$

Some examples of fitting data to that model are presented in Table II. Basing on time constants τ_1 and τ_2 we can differentiate healthy and burned tissues. The τ_2 time constant for healthy tissue is almost two times smaller then for full thickness burn. This can be explained as an effect of destruction of the blood micro-circulation system for a III-rd degree burn.

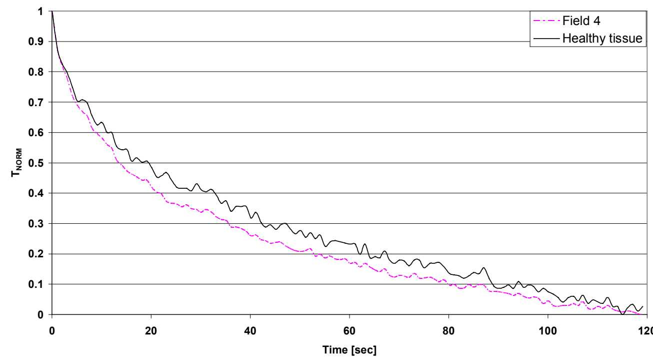


Fig. 5. Normalized temperature index for different areas: Field 4 and healthy tissue.

TABLE II
ESTIMATED MODEL PARAMETERS FOR SKIN - 48 HOURS AFTER INJURY

	T(t) = A₀+A₁*exp(-t/τ₁)+A₂*exp(-t/τ₂)				
	y_0	A_1	τ_1	A_2	τ_2
Field 4	-0.1869	0.4059	7.7896	0.7275	93.9447
Field 5	-0.1037	0.3762	6.3387	0.6901	65.3405
Field 6	-0.0475	0.2986	4.2824	0.7327	48.0630
healthy tissue	-0.0806	0.2980	5.3831	0.7663	55.7929

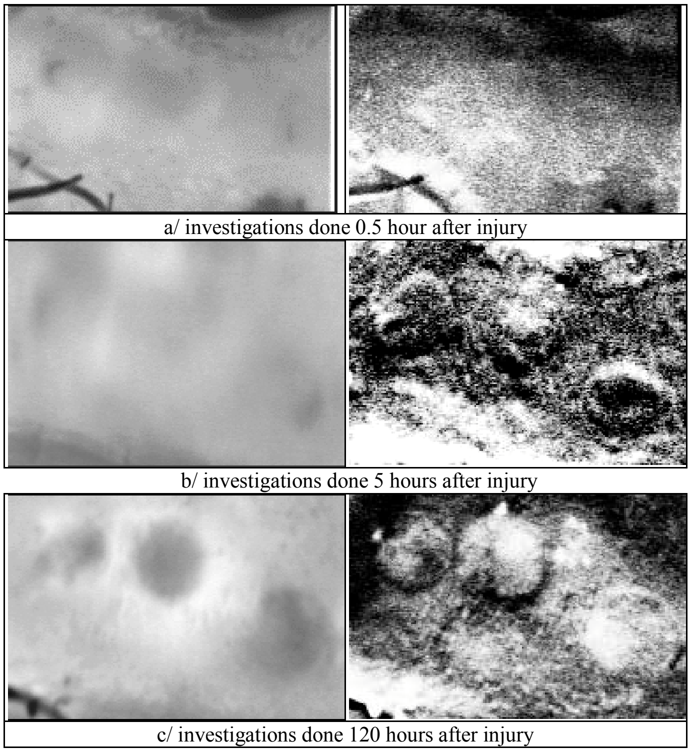
D. Pulse Thermography

As an example of parametric images the NDPTI (Normalized Differential Pulse Thermography Index) pictures are shown in Fig. 6. The proper image processing can generate so-called “hot spots” and “cold spots” images. We define the NDPTI [7] as:

$$NDPTI(x,y,t) = \frac{T(x,y,0) - T(x,y,t)}{T(x,y,0) + T(x,y,t)}, \tag{3}$$

where: *x, y* - pixel co-ordinates, *0* – moment of excitation switching *on* or *off*.

The images are calculated for fields 1, 2, 3 for different times after the burn injury procedure. For comparison also static thermograms taken at the same moments are shown. It is impossible to make any quantitative analysis basing on classical thermograms. We claim that in active thermography correlation between the thickness of the affected tissue and the related time constant is possible. Still, some important observation should be underlined. Data from the thermogram taken 30 minutes after the injury are not very informative. It seems that after 30 minutes following the accident the physical changes of injured tissues are too small for differentiation by thermographic measurements. This is because the process of tissue necrosis just started. Much more evident differences are seen 5 hours after the accident. Differences between healthy an injured tissue are even more clearly visible at the 5-th day of investigation but this is due to formation of a layer of dead tissue which has completely different thermal properties from living tissues. This information is of rather low diagnostic meaning in terms of early medical interventions.



a/ investigations done 0.5 hour after injury

b/ investigations done 5 hours after injury

c/ investigations done 120 hours after injury

Fig. 6. Burns 2, 3, 4 for the pig No 2 - left -static thermograms (temperature range $29^0C - 39^0C$); right - NDPTI images obtained for 120 seconds.

IV. Discussion

Important conclusion drawn from the results *A* (investigation performed during the burn injury process) is that for the first aid it is of the highest importance to increase the heat exchange to surroundings by intensive cooling the injured area by cold air or even better by cold water.

We also proved in results *C* that the dynamic thermography can by applied in medical procedures for monitoring the state of the skin and subdermal tissue structure. The moment of thermographic investigation after an accident is of the highest significance. To our experience the most valuable results are obtained several hours after an accident but not letter that on the second day following an accident because healing process is affecting the measurements.

The work is still under development. We will continue *in vivo* experiments on animals (pigs) with fully controlled conditions of interventions, as this is the only objective and fast method to get reliable and scientifically valuable information. Our main effort will be directed to improve the measurement procedures to allow higher contrast between different classes of tissue with different thermal properties. We are still basing on very simple equivalent models, which are build to satisfy the experiment conditions and seem to be sufficient only for preliminary diagnostic conclusions. Therefore the second important goal is to introduce more sophisticated thermal model, adequately describing the behavior of thermal processes in living tissues. Further study on the correlation between thermal time constants of the model and observed real depths of burn lesions are necessary.

V. Conclusion

The main goal of the research – to find if the active thermography may be applicable in medical diagnostics for burns evaluation is positively verified. The dynamic thermography can by applied in medical procedures for monitoring the state of the skin and subdermal tissue structure during burns treatment giving objective, measurable ratings of the treatment procedure.

Diagnostic value of active thermography in clinical practice is still under evaluation. It seems to be very useful in open heart intra-operation monitoring for evaluating progressing heart infract [9] or immediately effect of a treatment resulting in increase or decrease in the blood flow in the muscle.

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